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Application of Nanocrystalline FeCuNbSiB Ribbon to a Noise Filter

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This paper describes the application of an Fe-based nanocrystalline ribbon to a common-mode noise filter in the 1 MHz ~1 GHz frequency range. A 10 μm thick Fe-based nanocrystalline ribbon was prepared by annealing an amorphous $Fe_{76.2}Cu_{1.0}Nb_{2.0}Si_{14.9}B_{5.9}$ ribbon at 570 °C for 10 min. in an transverse magnetic field of ≥ 80 Oe. We confirmed that this material had superior soft magnetic properties and exhibited the same noise attenuation effect as a conventional filter (ferrite core) but with 1/27th its volume.
Key words: nanocrystalline ribbon, noise filter

1. INTRODUCTION

Electromagnetic interference (EMI) is a growing problem for electronic equipment. A large amount of the EMI is caused by the radiated emission resulting from the common-mode noise current in cables which are used to connect digital equipment. Noise emissions from cables are suppressed by passing a current through cylindrical ferrite cores. In this configuration, the ferrite cores absorb the magnetic field caused by a common-mode noise current in the MHz ~ GHz frequency range. The ferrite cores, however, are too large to allow circuit boards or circuit units to be housed compactly.

We have investigated magnetic thin films (1) and magnetic ribbons(2) to realize high loss characteristics and a large attenuation for a common-mode noise in this frequency range. On the other hand, a new soft magnetic ribbon has been developed which consists mainly of fine crystals of Fe-Si solid solution with grain sizes of 10 ~15 nm(3). This Fe-based nanocrystalline ribbon had promising potential as an EMI noise filter material (4). Moreover, it was reported that its permeability was much enhanced by annealing in a transverse magnetic field (5). This paper describes high loss characteristics of an Fe-based nanocrystalline ribbon annealed in a transverse magnetic field and its application to an EMI noise filter which is much smaller than a ferrite core.

2. EXPERIMENTAL

A roll (5 mm in diameter and 12.5 mm long) of a 10 μm thick Fe-based nanocrystalline ribbon was prepared by annealing a preformed roll of a melt quenched $Fe_{76.2}Cu_{1.0}Nb_{2.0}Si_{14.9}B_{5.9}$ amorphous ribbon at 570 °C for 10 min. in an N_2 flow. The phases of the ribbon were identified to be an mixture of Fe-Si fine crystalline and amorphous phases by the X-ray diffraction method. During annealing, a transverse magnetic field, H_t, of 0~140 Oe was applied with a Helmholtz coil.

The static magnetic properties were measured with a B-H loop tracer. We measured its impedance ($Z=R+jX$, R : resistance, X : reactance) from 1 MHz to 1 GHz with an impedance meter. The sample was a roll consisted of a 6 cm long and 12.5 mm wide ribbon through which a 17 mm long current lead was passed. The complex relative permeability ($\mu_r = \mu_r' - j\mu_r''$) at 1 MHz was calculated from the impedance according to the following equation.

$$R=f\cdot\mu_r''\cdot\mu_0\cdot l\cdot t/r \quad (1)$$
$$X=f\cdot\mu_r'\cdot\mu_0\cdot l\cdot t/r \quad (2)$$

where f, μ_0, t, l and r are frequency, permeability of a vacuum, roll thickness, roll length and roll radius, respectively.

Figure 1 shows the noise current measurement setup. We measured the transmission coefficient, S_{21}, of the cable from 10 MHz to 1 GHz with a network analyzer. We used a 2.1 m long twisted pair cable with a characteristic impedance of 110 Ω. One end of the cable was connected to port 1 of the network analyzer via an impedance matching circuit and the other end was terminated with a resistance of 110 Ω. A section of cable at the input end was wrapped with a series of rolls (5 mm in diameter and 12.5 mm long) composed of the 30 cm long Fe-based nanocrystalline ribbons. A commercially available ferrite core (inner diameter: 9 mm, outer diameter: 16 mm, length: 28 mm, volume: 4 cc) was also used for comparison. Common-mode noise current, which is equivalent to S_{21}, was detected with a current probe.

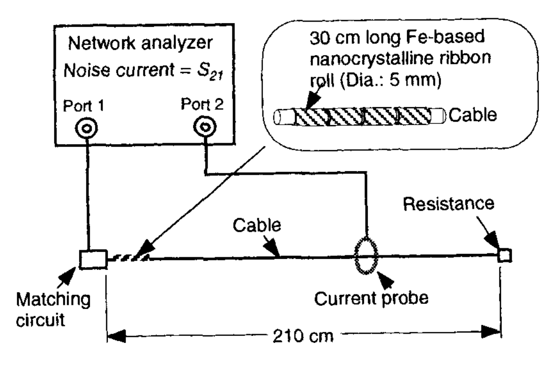

Fig. 1 Schematic diagram of the noise current measurement set up.

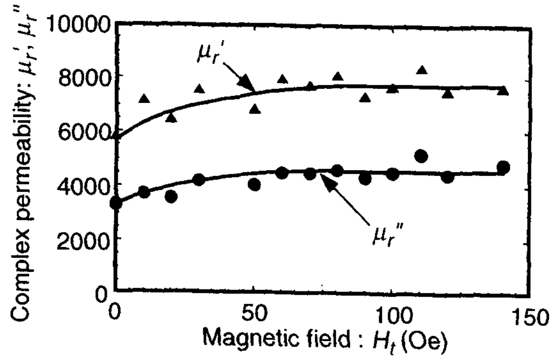

Fig. 2 Relation between transverse magnetic field, H_t, and complex relative permeability ($\mu_r = \mu_r' - j\mu_r''$) at 1 MHz. Solid circles and solid triangles are μ_r' and μ_r'', respectively.

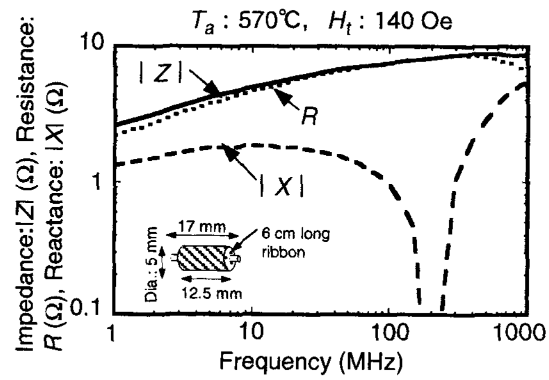

Fig. 4 Frequency dependence of the impedance ($Z=R+jX$) for a 6 cm long Fe-based nanocrystalline ribbon annealed in a transverse magnetic field of 140 Oe.

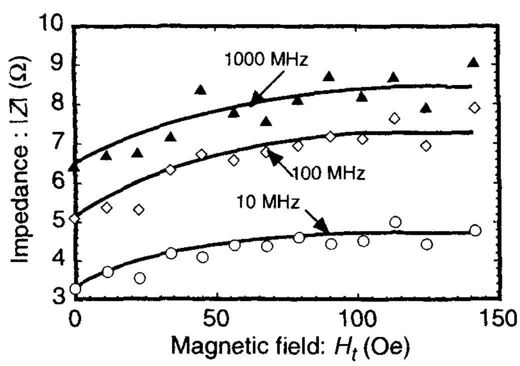

Fig. 3 Relation between transverse magnetic field, H_t, and the impedance at 10, 100 and 1000 MHz.

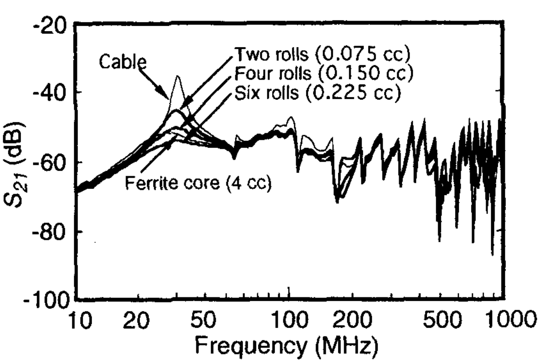

Fig. 5 Frequency dependence of S_{21} for a 2.1 long cable without a filter, with two, four and six rolls of the ribbons annealed in a transverse magnetic field of 140 Oe and with a ferrite core.

3. RESULTS AND DISCUSSION

Figure 2 shows the relation between H_t and complex relative permeability (μ_r': real part, μ_r'': imaginary part) at 1 MHz. The μ_r' and μ_r'' values for an Fe-based nanocrystalline ribbon annealed without a magnetic field were 3400 and 5900, respectively. As H_t was increased from 0 to 80 Oe, μ_r' and μ_r'' increased linearly and approached constant values (μ_r''= 4600 and μ_r'=7700) at H_t = 80~140 Oe. The coercive force was within the accuracy of the measurement (~0.02 Oe) over the whole H_t range. The soft magnetic properties at H_t= 80~140 Oe described above were in good agreement with previously reported data for a nanocrystalline FeCuNbSiB ribbon which was annealed in a transverse magnetic field (5): The weak induced anisotropy caused by transverse magnetic field annealing further enhanced the permeability.

Figure 3 shows the H_t dependence of the impedance |Z| at 10, 100 and 1000 MHz for a 6 cm long ribbon annealed at 570 °C. All |Z| values showed similar tendency to the permeability: |Z| increased as H_t was increased from 0 to ~80 Oe and then saturated. The all |Z| values at $H_t \geq 80$ Oe was about 50 % higher than those of a ribbon annealed at $H_t = 0$.

Figure 4 shows the frequency dependence of |Z|, R and |X| for a 6 cm long ribbon annealed at 570 °C in a transverse magnetic field of 140 Oe. R increased from 2 Ω at 1 MHz to ~ 9 Ω at 300 MHz and then decreased slightly with increasing frequency. |Z| increased from 2.5 Ω at 1 MHz to ~ 9 Ω at 1000 MHz with increasing frequency.

The above results suggest that the Fe-based nanocrystalline ribbon annealed at $H_t \geq 80$ Oe exhibits a large noise attenuation over the whole frequency range. In fact, this tendency of R and |Z| with increasing frequency is very similar to that of a conventional ferrite core, whose R and |Z| values increase from 20 Ω at

1MHz to ~200 Ω at ~300 MHz. The R and $|Z|$ values estimated for four rolls (120 cm long) of Fe-based nanocrystalline ribbons annealed at H_t=140 Oe were about 200 Ω above 350 MHz. These values are almost the same as those of the ferrite core. Consequently, the Fe-based nanocrystalline ribbon rolls were considered to have the same noise attenuation potential as the ferrite core.

Figure 5 shows the frequency dependence of S_{21} for a 210 cm long cable without a filter, with two, four and six rolls of the Fe-based nanocrystalline ribbon annealed at H_t= 140 Oe and with an ferrite core. Since the cable operates as a quarter wavelength antenna for a common-mode noise current, both the noise emission and noise attenuation were enhanced at the resonant frequency (~30 MHz) and at higher harmonic frequencies. As the number of rolls was increased from zero to six. the noise attenuation values at ~30 MHz increased monotonously from 0 to 17.8 dB. The noise attenuation value of the four rolls of the ribbon was ~15 dB, which was almost the same as that with the ferrite core. The total volume of the four rolls of the ribbon (0.15 cc) is much less than that of the ferrite core (4 cc). Consequently, it is confirmed that the Fe-based nanocrystalline ribbons annealed at H_t = 80~140 Oe make it possible to reduce the volume of an EMI noise filter to 1/27th of a ferrite core.

4. CONCLUSION

We confirmed that a 10 μm thick Fe-based nanocrystalline ribbon annealed at 570 °C for 10 min. in a transverse magnetic field above 80 Oe is a promising candidate for use in common-mode noise filters. The ribbon exhibits high loss characteristics based on the eddy current loss and is effective to decrease the volume of a noise filter.

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